320-to-10 Gbit/s all-optical demultiplexing using sum-frequency generation in PPLN waveguide

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A 320-to-10 Gbit/s all-optical demultiplexer based on sum-frequency generation in a periodically-poled lithium niobate (PPLN) waveguide is demonstrated. A bit-error-rate of 10⁻⁵ is achieved with a power penalty of 1.5 dB.

**Principle of operation:** The wavelengths associated with the data and control signals, schematically shown in Fig. 1, are assigned to fulfill the conditions for SFG in the PPLN satisfying the relation \( \lambda_{\text{SH}} = \lambda_{\text{c}}^2 + \lambda_{\text{s}}^2 \), where \( \lambda_{\text{c}} \) and \( \lambda_{\text{s}} \) denote the data and control signals, respectively, and \( \lambda_{\text{SH}} \) the wavelength of frequency-doubling of the PPLN. Normally, \( \lambda_{\text{SH}} \) is also called the quasi-phase matching (QPM) wavelength. The wavelengths ranges satisfying this relationship are \( \lambda_{\text{SH}} \leq 2\lambda_{\text{m}} \), where \( \lambda_{\text{m}} \) is the wavelength of the highest signal. At the output of the PPLN, the extracted channels downconverted to 773.1 nm are detected by a 12 GHz GaAs/InP photoreceiver for BER performance evaluation.

**Experimental setup:** A schematic of the experimental procedure is shown in Fig. 2. Optical pulses generated by a fibre modelocked laser (FMLL) with a pulse width of 1.5 ps at 1550 nm and 40 GHz repetition rate are amplitude modulated to form a 2¹ – 1 return-to-zero on-off keying (RZ-OOK) PRBS stream. The pulses are compressed to 1 ps, tuned to 1559 nm and multiplexed by a fibre-based interleaver to form the 320 Gbit/s OTDM signal. The control signal has a pulsewidth of 2.5 ps at 1541 nm and 10 GHz repetition rate. To resolve the data signal in the optical demultiplexer, the pulses were compressed to 1.2 ps and tuned to 1533.6 nm. The timing jitter of the control signal after pulse compression obtained from phase-noise measurements is 45 fs. The wavelengths of the data and control signals which satisfy SFG are coupled into the PPLN with the corresponding average power of 11 and 10 dBm. To select a particular channel of the OTDM signal, a tunable optical-delay line is placed in the path of the control signal.

The PPLN consists of a temperature-controlled and pigtailed 30 mm waveguide, the QPM of which at 52°C peaks at 1546.2 nm (\( \lambda_{\text{SH}} = 773.1 \) nm) with a normalised efficiency \( \eta_{\text{norm}} = 214 \% \text{W}^{-1} \). It holds a area between the signals is upconverted to the visible region and corresponds to the extracted channel. The extracted signal in question presents no intra-channel interference owing to the existing separation between pulses that corresponds to the period of the extraction rate. Inter-channel interference is avoided by controlling the control pulse width. Finally, the extracted channels are detected by a photoreceiver to drive a bit-error-rate (BER) tester.
The attained average power penalty is less than 1.5 dB. The spectrum of the control pulse together with the spectrum of the 320 Gbit/s OTDM signal are placed in a conjugate-sided fashion with respect to the QPM wavelength. The corresponding wavelengths were assigned not only to satisfy the SFG process but also to reduce the amount of noise at the QPM wavelength. When the SFG process is satisfied, the extracted channel is selected by tuning the optical delay. This implies an overlapping or cross-correlation between the pulses of the control and data signals, downconverting the target channel to \( \lambda_{320} \), the width of which is broadened from 1.2 to 10.2 ps (1.2 ps + 0.3 ps/mm x 30 mm) owing to the GVM. Since every 100 ps (the period of the control signal) a pulse is extracted, no intra-channel crosstalk is revealed. Fig. 3b shows the optical spectrum and time-domain trace of a 10 Gbit/s extracted channel. The width of the pulses is due to the combined effect of the impulse response of the photoreceiver and the oscilloscope. If the control pulses are not adequately compressed (as defined by the data bit-slot), inter-channel crosstalk will be experienced.

The BER performance of the PPLN-based demultiplexer is shown in Fig. 4. The circles illustrate error-free operation of a 10 Gbit/s single channel at 850 nm used as reference. The full and half-filled squares represent the best and worst case 320-to-10 Gbit/s demultiplexing performance. Error-free operation is achieved on all the channels with an average received optical power of \(-16.4 \, \text{dBm}\). This value corresponds to an average power penalty of 2 dB with respect to the reference. This penalty is due to a reduced OSNR and to the responsivity of the photoreceiver which is optimised for 850 nm. The OSNR for the 320-to-10 Gbit/s channel is 10.4 dB compared to 12 dB for the 160-to-10 Gbit/s case. BER curves for best and worst cases are also plotted in the same figure. The attained average power penalty is less than 1.5 dB. Finally, Fig. 5 shows the BER performance of \( 10^{-9} \) for 320 and 160 Gbit/s demultiplexed signals. Corresponding average optical powers of \(-16 \) and \(-17 \, \text{dBm}\) were attained.

Results: The spectra of the signals entering into the PPLN are shown in Fig. 3a. The spectrum of the control pulse together with the spectrum of the 320 Gbit/s OTDM signal are placed in a conjugate-sided fashion with respect to the QPM wavelength. The corresponding wavelengths were assigned not only to satisfy the SFG process but also to reduce the amount of noise at the QPM wavelength. When the SFG process is satisfied, the extracted channel is selected by tuning the optical delay. This implies an overlapping or cross-correlation between the pulses of the control and data signals, downconverting the target channel to \( \lambda_{320} \), the width of which is broadened from 1.2 to 10.2 ps (1.2 ps + 0.3 ps/mm x 30 mm) owing to the GVM. Since every 100 ps (the period of the control signal) a pulse is extracted, no intra-channel crosstalk is revealed. Fig. 3b shows the optical spectrum and time-domain trace of a 10 Gbit/s extracted channel. The width of the pulses is due to the combined effect of the impulse response of the photoreceiver and the oscilloscope. If the control pulses are not adequately compressed (as defined by the data bit-slot), inter-channel crosstalk will be experienced.

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Conclusions: A successful all-optical demultiplexing scheme for 320-to-10 Gbit/s employing a periodically-poled lithium niobate waveguide is presented. By exploiting the sum-frequency generation non-linear process, the bit-rate is limited by the pulsewidth of the control pulse. Error-free operation is achieved for all the channels attaining an average power penalty of 2 dB. The results here outlined demonstrate the potential offered by PPLN waveguides in ultra-high-speed optical signal processing.

References: